Completing the K-band Celestial Reference Frame in the North

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Abstract 22 GHz (K-band) radio observations have the potential to form the basis for the most accurate celestial reference frame ever constructed. Relative to the standard 2.3/8.4 GHz (S/X) observing bands, K-band is expected to exhibit a reduction in extended source morphology and core-shift. This reduction in astrophysical systematics should allow for a more stable celestial reference frame at K-band and should also be advantageous in tying the VLBI radio frame to the Gaia optical frame. The current K-band catalog consists of only 279 sources from ten Very Long Baseline Array (VLBA) sessions producing uncertainties in source positions at the ∼100 µas level. Given that southern K-band observations in the mid-south and over the south polar cap are under way, this paper returns attention back to the north. Further, given that the VLBA's 2 Gbps data rate is now 16 times better than that used in the original northern K-band observations, the resulting four-fold increase in sensitivity makes now an opportune time to re-visit K-band celestial frame work in the north. Therefore, we have initiated a new program of astrometric and imaging observations in the north using the VLBA to improve K-band astrometric precision and spatial coverage as well as to map the intrinsic source structure so that their astrometric quality can be evaluated. Our goal is to have at least 500 sources in the final K-band reference frame. This paper discusses the initial results from the first two of four approved K-band VLBA sessions.

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1 Background

At the standard S/X frequencies, many ICRF radio sources exhibit spatially extended structure that may vary in both time and frequency, degrading the accuracy of estimated source positions.

On VLBI scales sources tend to become more compact and show reduced core-shift at shorter wavelengths (higher frequencies). Both of these improvements allow for a more well-defined and stable reference frame at higher frequencies, such as K-band. This will be particularly advantageous in tying the VLBI reference frame to future optical reference frames such as Gaia. Astrometric and imaging observations by Lanyi et al. (2010) and Charlot et al. (2010) provide a foundation for the development of a reference frame at K-band.

The current K-band catalog (see Figure 1) consists of only 279 sources with weak coverage in the southern hemisphere, several localized regions with no sources, and median uncertainties in source positions at the ∼100 µas level. Dedicated observations to improve the precision and spatial coverage of the K-band CRF are currently underway.

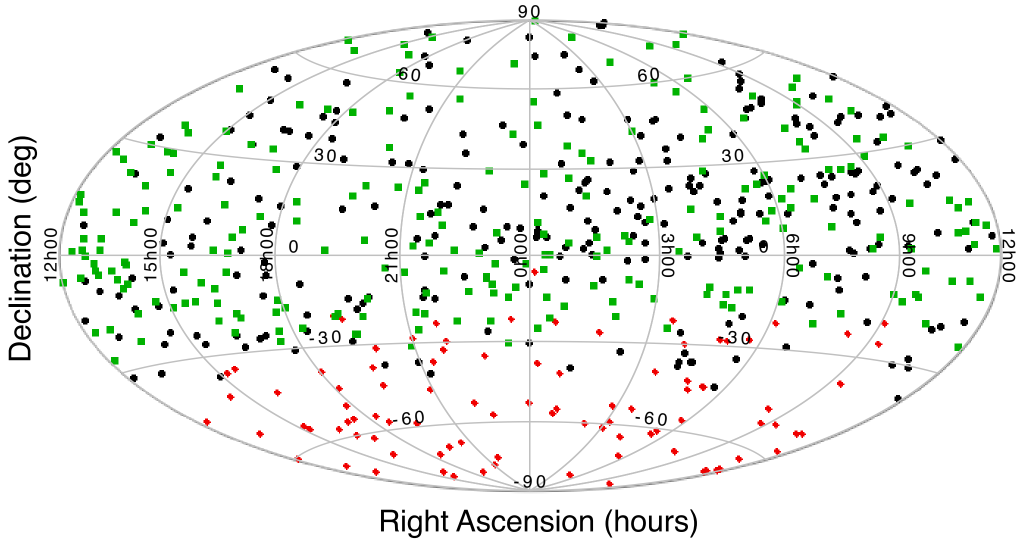


Fig. 1 The 279 sources from Lanyi et al. (2010) and Charlot et al. (2010) are shown in black. The 246 sources being observed using the VLBA are shown in green. The 106 sources from the southern astrometric observations are shown in red (de Witt et al. 2015).

2 Goals

Our goal is to realize by 2018 a full-sky, K-band celestial frame with accuracy better than 70 µas to match the Gaia predicted accuracy for visual magnitudes at V≈18. We are also aiming to densify the K-band frame in the north using the Very Long Baseline Array (VLBA) and to produce a sky coverage in the southern hemisphere comparable in density and accuracy to that obtained from the astrometry done with the VLBA in the northern hemisphere. Figure 1 shows the sky coverage at K-band of previously observed sources plus the additional sources that we are in the process of observing. In black are the 279 sources previously observed by Lanyi at al. (2010) and Charlot et al. (2010); in green are the 246 sources currently under observation using the VLBA; in red the 106 sources coming from the southern hemisphere observation program using South Africa to Australia baselines (de Witt et al. 2015). Thus Figure 1 shows the need for improving the sky coverage both in the south (red sources) and the north (green sources).

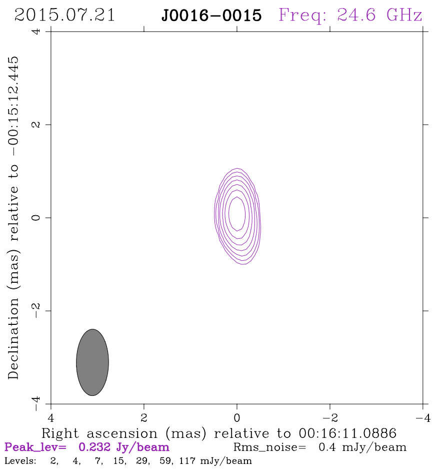
3 K-band CRF in the North

We have partially completed a project, BJ083, with the VLBA to observe 264 sources. The source list is based upon the 8.4/32 GHz (X/Ka) catalog (Jacobs, 2014). The selection criteria were set to have sources above about -30° declination and flux cut-off of $\sim$100 mJy. Two of the four 24-hour sessions scheduled were already observed. There are two additional VLBA observing sessions already approved which will be used to observe the rest of the sources from our list of 264 total candidates.

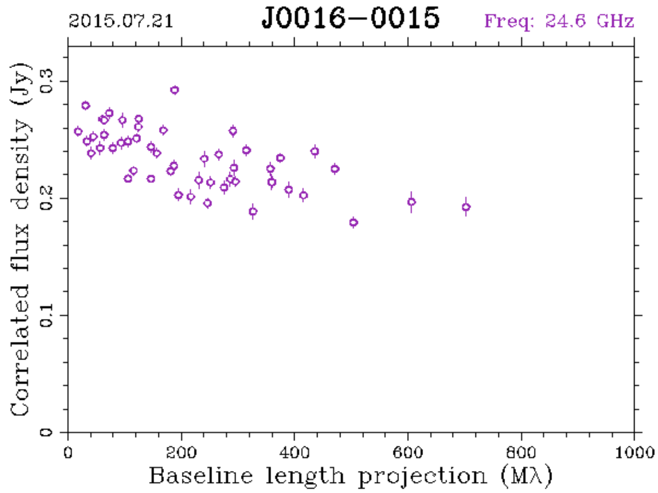
4 Preliminary Imaging Results from the VLBA

Our imaging pipeline started with correlation using DiFX (Deller et al, 2007), fringe fitting with PIMA (Petrov, 2011), and finally the imaging itself used DIFMAP (Shepherd, 1997). For the astrometric observable extraction, the data were fringe fitted using the Haystack Observatory Postprocessing System (HOPS). Physical modeling and parameter estimation will use JPL's MODEST software (Sovers, Fanselow, Jacobs, 1998).

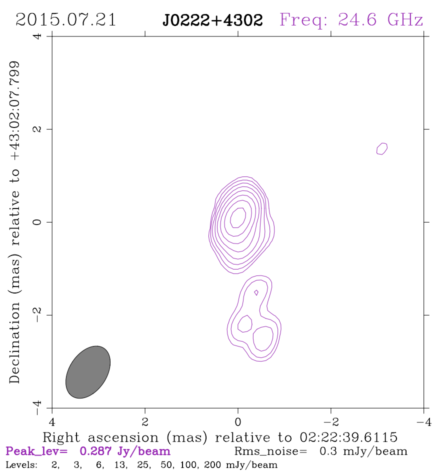
We now have initial results for 108 sources from our first VLBA session (BJ083a: 2015 Jul 21). Figure 2 shows images and visibility plots (north is up and east is to the left) for a representative sample of six out of the total of 108 sources analyzed so far.



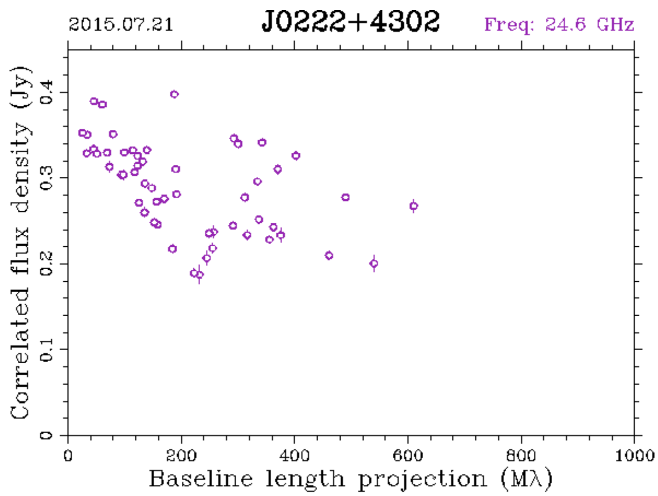
2.1a. Image J0016-0015. Near the equator: more challenging to get good UV coverage. Very compact.



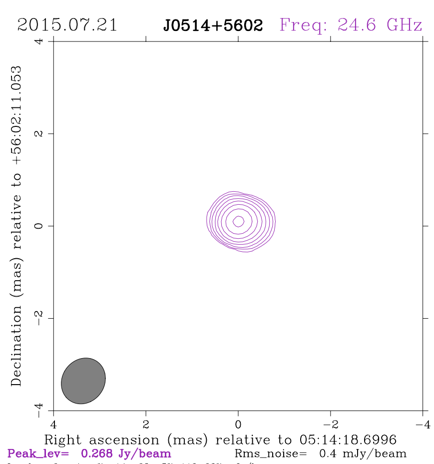
2.1b. Visibility J0016-0015: Flat flux vs. projected length.



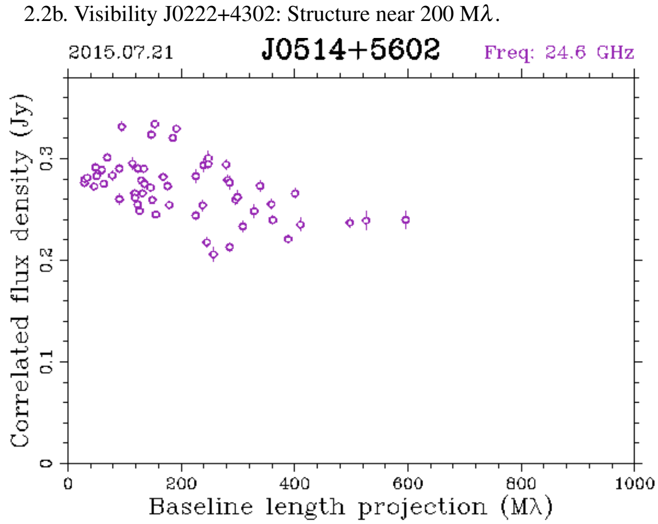
2.2a. Image J0222+4302: Feint structure to the south.



2.2b. Visibility J0222+4302: Structure near 200 Mλ.

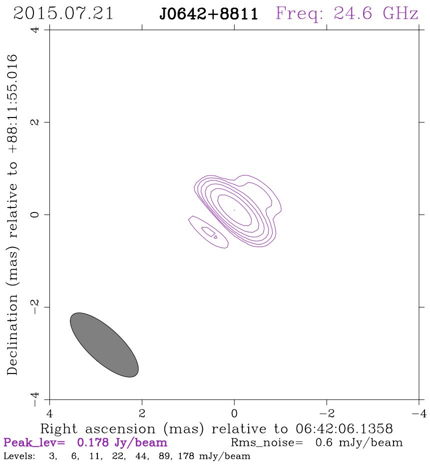


2.3a. Image J0514+5602. Very compact on mas scales.

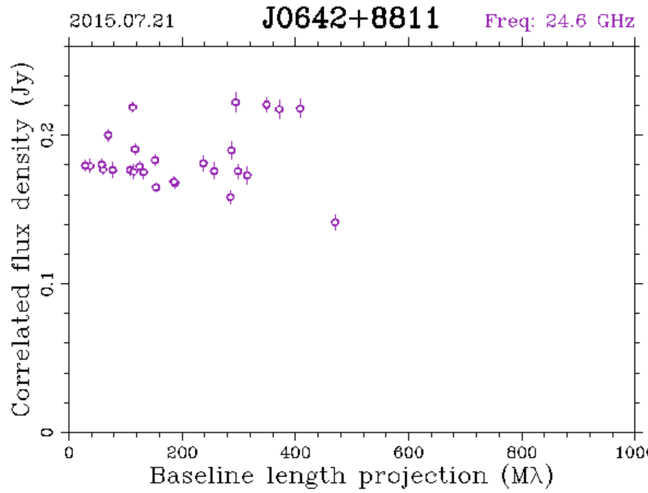


2.3b. Visibility J0514+5602: Very flat flux vs. projected baseline length.

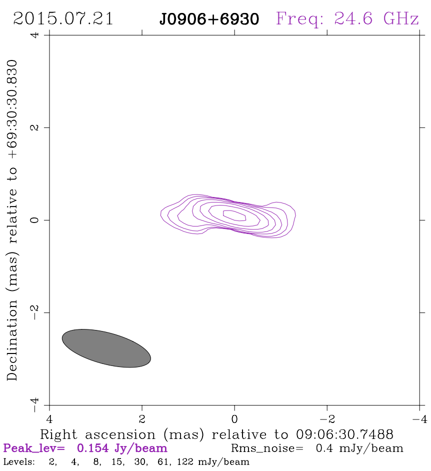
Fig. 2 Images and visibility plots from VLBA K-band CRF data.



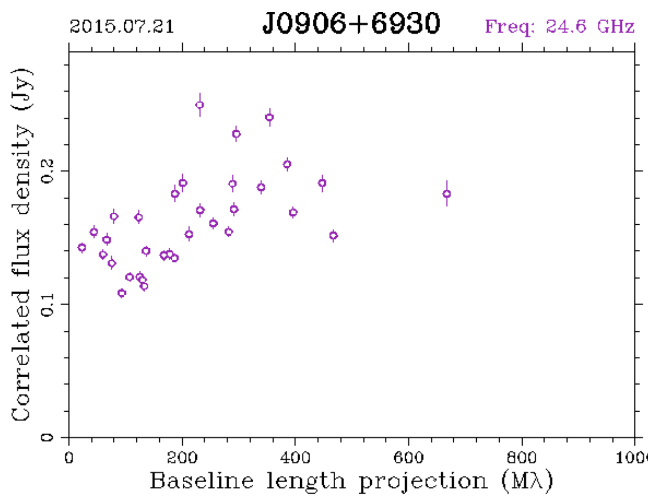
2.4a. Image J0642+8811. Extended to NE. Source is within 2° of North pole: potential for excellent UV coverage.



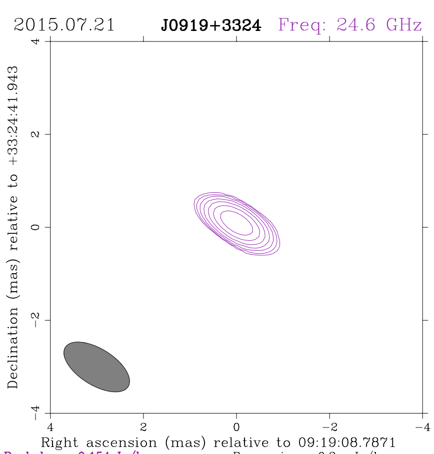
2.4b. Visibility J0632+8811.



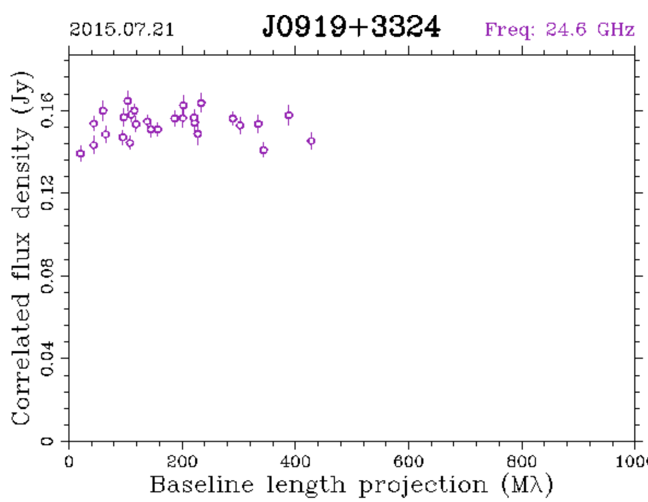
2.5a. Image J0906+6930. At redshift 5.5 this is the most distant quasar in our celestial frame. Circumpolar sources allow good UV coverage. Note anti-symmetric extension.



2.5b. Visibility J0906+6930. Redshift 5.5. Note the increasing flux vs. projected baseline length.



2.6a. Image J0919+3324. Very compact on mas scales.



2.6b. Visibility J0919+3324. Very flat flux vs. projected length.

Fig. 2 Images and visibility plots from VLBA K-band CRF data (cont'd).

These six sources were chosen to represent a wide range of declinations ($\delta = 0^\circ$ to $\delta = 88^\circ$) which leads to wide range of potential UV coverages. In particular, sources north of $\delta \approx 60^\circ$ will be above the horizon at all times and thus have potential for excellent UV coverage from the rotation of the baselines through the 24-hour session. On the other hand, given that the VLBA is an all northern array, sources near the equator such as J0016−0015 will be visible for a rather limited range of hour angles and thus the UV coverage in general will be at a disadvantage compared to circumpolar sources. We have also included some sources at mid-northern declinations (J0919+3324, J0222+4302) and a near circumpolar source (J0514+5602) to give a a wide sampling of the expected quality of UV coverages.

5 Conclusions

In an effort to realize a more accurate celestial reference frame by leveraging more compact source structures and smaller core shifts, we have begun a program of observations at K-band.

We report here on our northern K-band VLBA program from which 108 of 264 planned sources have now been mapped. Work to complete images of all 264 sources and to estimate astrometric positions is underway. This northern data, when combined with our complementary southern program using HartRAO, AuScope, and Tidbinbilla, is expected to produce a full-sky K-band reference frame with a median precision of ≈70 µas by 2018 in order to be considered the ICRF-3 (radio) and to be ready for comparison with the Gaia (optical) frame.

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